Augmented Urban Planning Workbench: Overlaying Drawings, Physical Models and Digital Simulation

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Abstract

There is a problem in the spatial and temporal separation between the varying forms of representation used in urban design. Sketches, physical models, and more recently computational simulation, while each serving a useful purpose, tend to be incompatible forms of representation. The contemporary designer is required assimilate these divergent media into a single mental construct and in so doing is distracted from the central process of design.

We propose an Augmented Reality Workbench called "Luminous Table" that attempts to address this issue by integrating multiple forms of physical and digital representations. 2D drawings, 3D physical models, and digital simulation are overlaid into a single information space in order to support the urban design process.

We describe how the system was used in a graduate design course and discuss how the simultaneous use of physical and digital media allowed for a more holistic design approach. We also discuss the need for future technical improvements.

1. Introduction – The Urban Design Process

Urban designers shape the construction of cities in order to provide surroundings that are healthy, stimulating, and sustainable. In doing so, they are faced with the challenge of communicating their spatial concepts and ideas to the broader public.

Three Forms of Representation in Urban Design

In order to express their vision, urban designers commonly employ the following modes of representation (Fig. 2):

- **Drawings** on sheets of papers (two-dimensional) Hand-drawn sketches, scaled plans, diagrams, maps, satellite photographs (drawn or printed)
- **Physical Models** (three-dimensional) Physical scaled models of buildings and landscape.
- **Digital Models** in computers (two and three-dimensional) Digital models of buildings and landscape, simulation models and analytical tools of light, shadows, wind, and traffic flow.

By 'triangulating' between these multiple forms of representation, we gain a more realistic sense of the site and proposed urban design. Mitchell and McCullough (1995) articulated the many different forms of representation within a design process [7] (Fig. 3).

Note that each form of representation often remains separated from the others in time, space and scale. Drawings on a wall, physical models on a table, and digital models in a computer screen are created and displayed independently (Fig. 4).

Figure 1. Urban planning students using the *Luminous Table* in the design studio.

	two-dimensional	three-dimensional
physical	**drawings** on papers	**physical models**
digital	**digital models** and computational **simulation** & **analysis**	

Figure 2. The three primary modes of representation used in urban design.

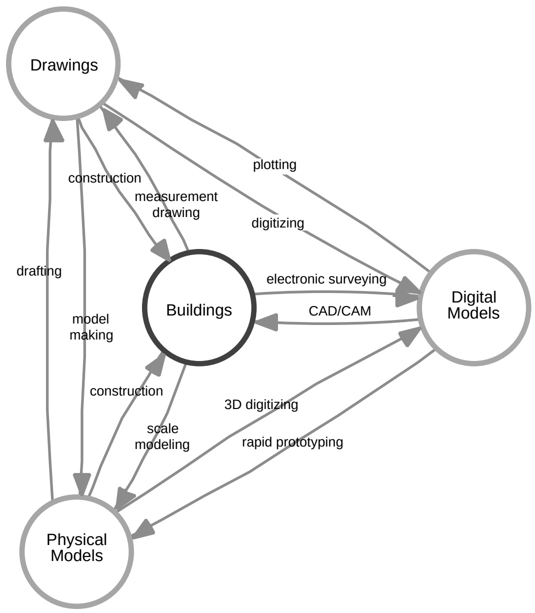


Figure 3. Traditional (physical) and digital media for design studio (cited from [7]).

(a) drawings

(b) physical models

(c) digital analysis

Figure 4. Conventional two-dimensional drawings, three-dimensional physical models, and digital representation techniques used in a traditional urban planning course

The spatial and temporal separation between the forms of design representation increases the cognitive load on the urban designers who is required to draw relationships between dislocated pieces of information during design sessions. Converting the media between digital and physical representations is technically possible in non-real-time manner, but it is time consuming and distracts the designer from focusing on the task.

The urban designer is in critical need of a platform that allows the simultaneous understanding of a wide variety of representations, including drawings, physical models, and digital analysis. After observing the urban planning process, we concluded that simultaneous use of physical and digital media in the same space is an important requirement of the design studio of the future.

2. The Luminous Table

The Luminous table was conceived as a platform for multi-layered physical and digital representations. We hypothesized that by overlaying previously incompatible representations at the same place and scale, we could provide a hybrid but seamless information space that would enrich the urban design process.

2.1. System Architecture

First, we lay out drawings, sketches and other scaled two-dimensional materials such as maps and satellite photos on the 4.0m x 1.4m work surface of the Luminous Table. Next, we place physical three-dimensional models, representing building components on top of these two-dimensional representations. Finally, two video projectors hanging from the ceiling project dynamic digital simulation onto the table surface. Two video cameras capture the activity on the table and adjust the dynamic representation according to the position of the drawings and models with optical tags. Fig. 5 illustrates this system architecture.

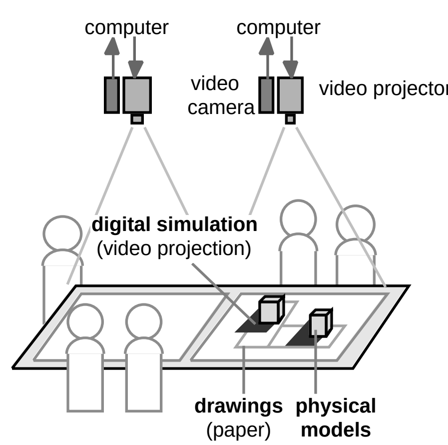


Figure 5. The Luminous Table supports multi-layering of 2D drawing, 3D physical models, and 2D video projection of digital simulation

2.2. Software

The software driving the Luminous Table installation had capabilities similar to Urp [8, 9], a proof-of-concept system that deployed a number of basic urban planning functions. The original Urp demonstrated a tangible interface approach to experimenting with (1) shadows cast by freely movable architectural units; (2) glare / reflections from architecture tagged as facade-reflective; (3) wind patterns arising from the arrangement of architectural elements; (4) a simple traffic simulation showing traffic patterns emerging from interactions among re-positionable road segments; and (5) proximity constraints among buildings and between buildings and roads.

While Urp fulfilled its purpose in demonstrating new tangible interaction techniques for urban planning, it was never developed thoroughly enough to be used for serious design work. By expanding Urp to meet the needs of an actual design scenario and testing it in the real design studio, we hoped to develop a design tool that was usable in real design practice.

2.3. Extension of Software Functionality

We built the Luminous Table software by extending the functionality of the original Urp software from a nascent “toy”-like form to a more mature form appropriate to a thorough design exercise. Our improvements to the original Urp software included:

Sun-shade computations

Buildings reflect glare from their facades and cast shadows on the ground. The shapes of these patches of light and dark are determined by the position of the sun in the sky, which is in turn depends three factors: the geographic latitude of the urban setting, the time of day, and the date. The original Urp simulation assumed fixed latitude and allowed time to be set only in discrete increments of one hour. The Luminous Table software allows greater flexibility by giving users the option to change the latitude and interactively set the date and time.

Increasing the temporal granularity of the simulation proved to be a valuable modification: students routinely performed intricate sun-shade studies, sometimes even observing the difference in shadow pattern resulting from a single day's change in date or over the interval of just a few minutes. This is an especially important issue in the design of public spaces that may be affected the construction of large nearby structures.

Traffic simulation

Urp's simulation of traffic effects was limited to linear two-lane road segments of fixed length with constant traffic flow. Traffic along intersecting roads would alternate, but the duration of the traffic cycle between these roads was also fixed. The new software for the Luminous Table was extended to allow the interactive adjustment of road length, road width (number of lanes), vehicular density, and traffic cycle time at each road in an intersection.

Architecture geometries

Urp was intended as a simple technology and interface demonstration. It used only a small collection of buildings, represented physically as carefully fabricated wire-frame structures and digitally as polygonal descriptions in a simple geometry description format. A working classroom system required substantial improvements, since it necessitated a large and elaborate arrangement of complex architectural structures.

We modified the original software to support building geometries that were created in the "shape file" format, as employed in a popular series of GIS-specific software from ESRI Inc. Models of urban structures throughout the U.S. are readily available in this format, which meshes well with other GIS-specific elements such as topography, waterways, and railroad infrastructure.

Save and load

Urp lacked the capability to save or restore work. Architecture, roads, diurnal time, and other initial parameters were specified using a text file that was parsed using the Vargle library. By implementing the objects as C++ classes with fine-grained serializing I/O support, we allowed the state of the entire system (or of any particular component) to be written out and later reconstructed for the purposes of continued design a presentation.

2.4. Combining TUI with GUI

Each of the functions available to the Urp was deployed using a physical tool tracked by the overhead camera. To engage the wind simulation, for example, the experimenter placed the "wind object" in the workspace and pointed it in the desired wind direction. Touching a “material wand” to a building initiated a glare study, transforming the building’s facade to shiny glass and producing computational reflections.

This tool-based approach had two disadvantages. First, the dense arrangement of buildings in a real-world design scenario created a table too cluttered to allow the use of tools. Second, although the computer vision system had sufficient resolution to precisely track the position and orientation of building models, it was unable to track the clock position to one-minute resolution.

Since overcrowding and display resolution constraints made a purely TUI-based approach impractical in the more complex Luminous Table system, we settled on a hybrid TUI/GUI approach. The hybrid system allowed students to use a mouse to change variables such as time of day and traffic cycle timing.

3. Related Work

The system architecture of the Luminous Table and its precursor Urp borrow heavily from pioneering work in Augmented Reality (AR) such as DigitalDesk [10], which demonstrated the fusion of physical and digital documents on a table with a video camera and projector pair above it. Video Mosaic [5] applied a similar AR technique to integrate a paper storyboard and an online digital video editing system.

There are several AR systems for urban design application that incorporate tangible interfaces, including most notably The Envisionment and Discovery Collaboratory (EDC) [1] and BUILT-IT [3]. The EDC, developed at the University of Colorado at Boulder, focuses on the creation of shared understanding through collaborative design using an augmented table and wall-size screen. By using a horizontal electronic whiteboard, participants work around a table, incrementally creating a shared model of a problem. They interact with computer simulations through the movement physical objects, which are recognized by a touch-sensitive projection surface. In their efforts to frame and resolve the problem, the stakeholders can collaboratively evaluate and prescribe changes by changing the placement of the objects on the table. Meanwhile, on a second vertical electronic whiteboard, the information being manipulated is relayed for all to see [1].

The BUILT-IT system, developed at the Swiss Federal Institute of Technology and the Technical University at Eindhoven, demonstrated the use of small Lego-like bricks to control the position and orientation of virtual buildings on a large computer screen. People seated around a table, interact with objects in a virtual scene. A plan view of the scene is projected onto the table where object manipulation takes place. A perspective view is simultaneously projected on the wall [3].

The Luminous Table is different from previous urban planning systems in that it focuses specifically on the integration of dynamic digital simulation with traditional physical medium such as sketches, maps, and scale models. This contrasts to Urp which only allowed physical models and digital simulation to be used simultaneously and made no allowances for sketches or paper maps.

4. Introduction of the Luminous Table to the Urban Design

We introduced the *Luminous Table* into an urban design class at the MIT School of Architecture and Planning during the spring of 2000. The class was composed of 11 students between the ages of 21 and 26. Most of the students had limited experience in professional design practice. The level of computer literacy in the class varied widely, with some students professing to be experts and others describing themselves as novices. The class was divided into three groups, and each group was asked to perform the same urban design exercise.

4.1. The Design Exercise

The design exercise was set by an independent instructor and provided an unbiased and highly specific test scenario for the *Luminous Table* platform. Here is an abridged version of the class instructor's description of the exercise:

The Site (Fig. 6)

The site for the design exercise is Kendall Square, at the heart of a district framed by MIT's campus, the Charles River and the East Cambridge neighborhood. The square has emerged as a focus of pedestrian life adjacent to MIT's campus and centered on the subway transit stop.

The Development

The Kendall Square development plan offers a vision of a highly urban use of community; a mix of biotech labs, residential properties such as condominiums and apartments, a hotel, and a broad range of retail amenities. The site, just across the road from our campus, is between a multitude of attractions and activities, and has the potential to reach out to neighboring population centers as a cultural, recreational and retail hub.

Figure 6. Aerial photograph of the site for the design exercise in the urban planning course

4.2. Methodology

After working with the *Luminous Table* over the course of one semester, students were asked to openly express their reactions to the *Luminous Table*.

While some informal observations were made in the classroom, the majority of our analysis was conducted by reviewing the ten hours of video footage we recorded using non-obtrusive cameras.

Since we were primarily concerned with the qualitative influences of the table on the design process, we did not attempt to use a quantitative methodology of analysis.

Since we did not expect the students to express their full sentiments in the public setting of the design studio, we also asked them to fill out a questionnaire about their experience with the Luminous Table.

5. Lessons from Design Studio

5.1. Conventional representation provides useful affordances

The *Luminous Table* provided a platform for the early stages of design that allowed students and their instructor to quickly sketch out proposals for urban development. Students frequently used yellow transparencies for rough design sketches, laying them on top of the site map, which was printed on a large sheet of paper (Fig. 7).

Figure 7. Students and Instructor discussing the design using sketches on yellow transparency on the *Luminous Table*

The *Luminous Table* also allowed students to physically model their work, helping them to gain a clear sense of the spatial implication of their designs (Fig. 8). The physicality of the models made it easy for students to manipulate the relationships between modeled forms. Both of these factors helped students considerably in communicating design intentions during their final presentations.

Figure 8. Students manipulating physical models on the *Luminous Table* surface

Unfortunately, the requirement that digital projections pass through the physical models onto the Luminous Table surface resulted in some constraints on model fabrication. The models were originally conceived as wire-frame assemblies to minimize the real shadow created by the light from the video projector (Fig. 9). However, this limitation detracted from the natural advantages offered by physical building models; one student pointed out, *"the empty walls detract from the model's ability to convey the sense of mass and volume."*

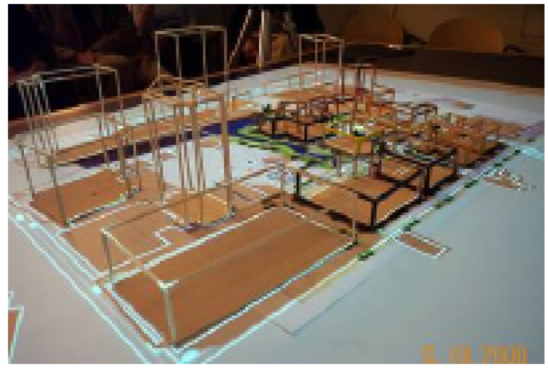


Figure 9. Wire-frame assemblies used in students' presentation. Lack of the sense of mass and volume became an issue.

To combat this reduced sense of mass and volume, we developed two alternative physical modeling techniques during the class. The first technique defined the building volume by representing each face in clear Plexiglas. This allowed projected light to pass through the building while more clearly communicating the building's volume. It also allowed the viewer to look at spaces both within and beyond the model. However, since building Plexiglas models is more time-consuming than building wire-frame models, this technique failed to meet our design goal of allowing the easy manipulation of physical, digital, and two-dimensional design forms.

Our most successful modeling technique represented building envelopes with laminated layers of Plexiglas (Fig. 10). This relatively simple process gave the building models more substance and made it possible to establish a sense of scale, with each layer of Plexiglas representing one floor of the modeled building.

Figure 10. Laminated Plexi-glass modeling technique devised to resolve the issue of wire frame model

Our changes to the building models increased the amount of information the models conveyed, but the necessity that the models be transparent remained a severe restriction. While the *Luminous Table* made great inroads in addressing this issue, it still fell short of conventional physical modeling techniques, which have the potential to evoke a far greater sense of a building's material palette.

5.2. Dynamic computational representation brings the physical models to life.

The *Luminous Table's* greatest strength is its ability to merge time based digital representations such as dynamic simulation with the more conventional modes of drawing and physical modeling. Students were quick to praise this aspect of the *Luminous Table*; as one student wrote, *"The Luminous Table highlighted aspects of the building site which are normally cumbersome to analyze and was excellent for bringing the site to life and showing it as a dynamic place which changes through course of day."*

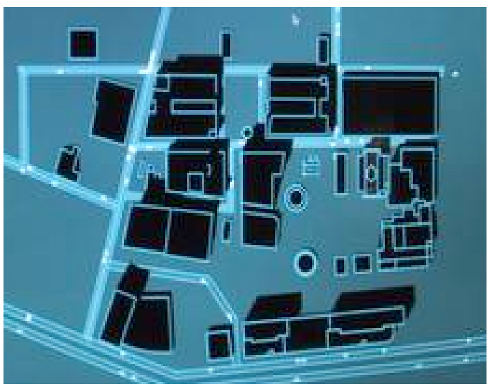


Figure 11. Dynamic digital sunlight/shadow and traffic simulation on a computer screen (This image was projected onto the *Luminous Table*.)

The ability to represent changing sunlight levels throughout the day was the most widely used aspect of the *Luminous Table's* dynamic modeling capability (Fig. 11). This application had been well developed and it was relatively simple for the students to gain a clear understanding of the influences of their designs on lighting levels. Some students suggested that it would also be extremely useful to simulate nighttime lighting conditions on the table.

The wind speed capability, though not as widely used, was important in influencing decisions on the size and positioning of public squares, building entrances, and other zones where wind speed was critical.

Students routinely performed intricate sun-shade studies, at times changing the date by only one day or the time by only a few minutes and observing the effects on the shadow patterns. This an important issue when considering the lunchtime lighting conditions of a public space surrounded by large structures.

The simulation of traffic density is an extremely complex exercise. Since the car flow model incorporated into the *Luminous Table* software was fairly rudimentary, the students did not use the traffic simulation as the basis of concrete design decisions such as road width or signaling plans. One student commented, *"I didn't find the road display useful at all. Two-way road objects would have helped, as would have somehow being able to curve roads."*

The table also allowed students to easily test design decisions in the context of dynamic entities. One student wrote, *"We were able to see that our linear system on the south end of the site would be sunny most of the time, which reinforced our conviction that this was a good intervention."*

Once the design decisions had been finalized, the table provided a simple means of communicating the rational behind design decisions based on complex dynamic systems.

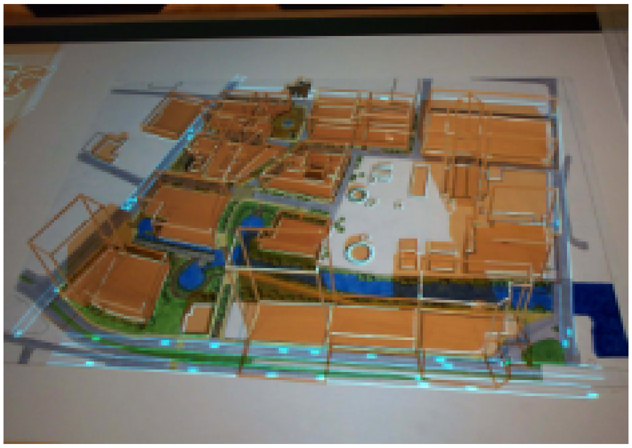
5.3. Information layering provides a holistic view.

While each of the time-based representations is useful in its own right, their true potential is realized only when they are considered in conjunction with the two and three-dimensional physical representations. In the conventional design studio, all of these representations are separated from each other spatially and temporarily (Fig. 4). The new relationships afforded by our layered multiple representations were summarized by a student who stated: *"The Luminous Table helped us to select public spaces with the most sunshine and then helped us decide on the heights of buildings."*

Clearly, this student was making a connection between the dynamic quality of sunshine and the spatial entity of the building height. In conventional practice, the urban designer conceives of a built form and may later test to see how this influences lighting conditions. In this case the form has followed from a decision that was based on lighting levels alone. One student described this change in the design process as follows; *"The table greatly facilitates decisions about building height, location and alignment with respect to sun/shade conditions and helped us recognize possibilities we had previously overlooked."*

Not all students were as inspired by this potential of the table: One student wrote, *"The Luminous Table… informed our process initially, as we kept the shadow issue at the back of our minds when developing the plan but it was definitely not the most important factor in dictating design."* One student even pointed out the potential dangers of using a tool that was extremely powerful in some respects but neglected other urban design factors: *"[The Luminous Table] only focuses on a few aspects of urban design and sometimes exaggerates their importance."*

(a) drawings (b) physical models (c) digital simulation



(d) multi-layered representations: (a) + (b) + (c)

Figure 12. Multi-layering of three representational techniques used in the Luminous Table for the design studio project

Still, most students agreed that the multiple simultaneous representations provided by the Luminous Table made it easier to understand the dynamic interdependence of planning issues.

5.4. Synchronization among layers requires a robust tracking mechanism.

Fig. 12 illustrates three representation techniques: (a) drawings, (b) models, and (c) digital simulation, (d) integrated on top of the *Luminous Table* by multi-layering them with the same scale. To make the multi-layered information space work, spatial and temporal *synchronization* among the layers becomes important.

Students manually placed physical models on specific locations on the drawing based on the plans the students were exploring. A video camera and a computer vision program synchronized the location and orientation of physical models and the digital simulations influenced by the buildings. During the design studio, we encountered stability problems in tracking building models using computer vision due to the difficulty controlling the ambient light. The limited size of building models also made it difficult to attach the reflective colored dots used as optical tags, discouraging students from using this vision-based automatic tracking function. Instead, students chose to synchronize the position of physical models and their digital counterparts manually using the computer mouse when necessary, rather than tagging the models and relying on an unstable computer vision system. This strongly suggests the necessity of developing more robust multiple object tracking technology on a large table surface.

5.5. Large table facilitated collaboration and communication.

The *Luminous Table* was largely successful in allowing collaborative design. As opposed to the standard Graphical User Interface (GUI), where a single user has dominance over the relatively small workspace of the screen, the *Luminous Table* provided a more equal footing for collaborative design. The ergonomics of the table allowed the entire design team to simultaneously work on a single design scheme (Fig. 13).

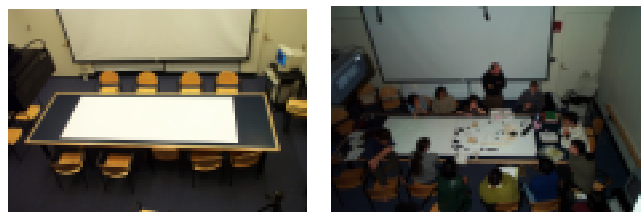


Figure 13. The Luminous Table providing a natural platform for group collaboration

Although no presentations were made to public during the course, the urban design students recognized the *Luminous Tabl's* potential for to ***"****Involve people who don't have expertise in the field."*

However, some students felt that the table's novel technology may have distracted from the concepts that the students were trying to communicate. Indeed, most of the discussion during the final presentations revolved around role of technology in design and focused less on specific conceptual aspects of the students' work.

During presentation periods, we discovered that the limited size of the table meant that some attendees were not able to see the specific elements to which the presenter referred. We addressed this issue by using a handheld video camera to project the area of focus onto a presentation screen. This enabled the presenter to focus attention on a specific issue while successfully communicating to all members of the audience (Fig. 14).

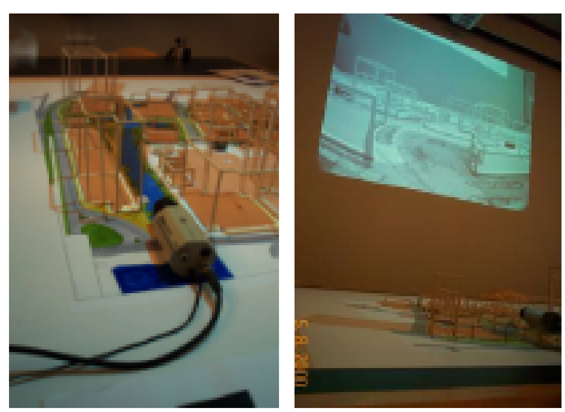


Figure 14. The handheld video camera (left) and video projection on a wall (right) used to display

close-up shots of three-dimensional view on the *Luminous Table* during project presentation

6. Conclusion

The central aim of the *Luminous Table* project is to integrate the three most broadly used forms of representation in the urban design process: drawings, physical models and digital models. By overlaying these representations, the *Luminous Table* provides a useful means to integrate divergent media.

6.1. Advantages of Tangible Interaction

Our experience in using the *Luminous Table* in the classroom setting has shown that it successfully combined the physical immediacy of conventional models and drawings with the power of digital simulation. We have shown how the system provides users with a means of understanding the relationships between the static form of physical models and the dynamic behavior of previously intangible factors such wind speed, shadow movements and vehicular flow. We have also highlighted some of the drawbacks of incompatibility and synchronization that arise in attempting to merge these physical and digital representations.

6.2. Broader Perspective Enabled by Layered Information

This paper has shown specific examples of how the layering of two-dimensional drawings, three-dimensional physical models, and dynamic digital simulation allowed the discovery of complex correlations between physical, social and dynamic factors involved in the design. Students and visiting observers agreed that this layering of information enabled students to respond with a more informed design.

6.3. Encouragement of Social Interaction

The ergonomics of the *Luminous Table* encouraged designers to communicate directly through voice, facial expression, and body language in reference to the representations of their plans. The large physical size of the *Luminous Table* allowed collaborators to simultaneously engage in the design process. This is in contrast to the standard computer interface that tends to discourage collaboration around a screen that was only designed for one user.

Elements of the *Luminous Table* can be manipulated with ease, allowing non-specialists to enter into the design process. In this way the Luminous Table has the potential to transform public presentations into a means of participatory design.

6.4. A seamless Creative Space

As one visiting critic pointed out, *"A successful design tool must stimulate creativity as well as solve problems."* By combining the benefits of multi-layered representation, the possibility for tangible interaction, and by providing a platform for meaningful collaboration, the *Luminous Table* goes some way in meeting this goal.

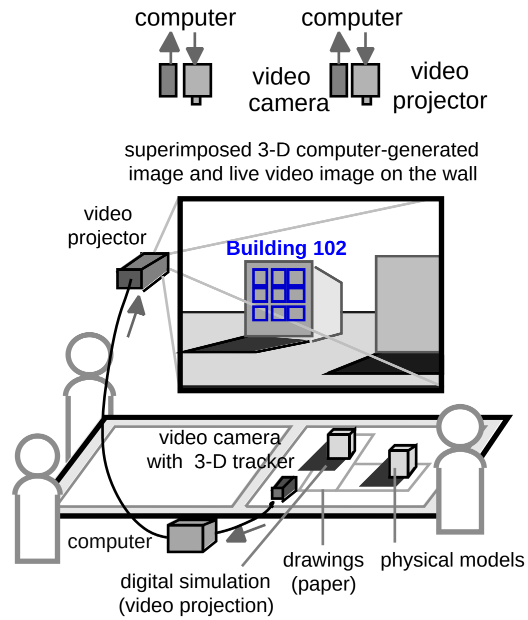


Figure 15. Wall projection of superimposed 3-D computer-generated image on the live video image of the *Luminous Table* captured by a small video camera with position tracker

7. Future Work

The *Luminous Table* is in the very early stages of development both as a concept and as a working prototype and is in need of both technical and social design improvements. Future goals for future research include:

- improving the synchronization between the physical and digital models using robust sensing technology,
- increasing the sophistication of wind and traffic simulation,
- enriching the tools for manipulation of digital and physical form on the table,
- creating additional dynamic factors including: drainage vectors, microclimate analysis, topographical information, auditory mapping, nocturnal illumination analysis, pedestrian flow modeling, vegetation and erosion dynamics,
- developing a means to import and export digital models from more sources,
- providing a means for using the Luminous Table as a platform for distance collaboration, and
- exploring means of augmenting the video image from the small handheld video camera by superimposing three-dimensional computer graphics and projecting on the wall as illustrated in Fig. 15 to extend the use of wall in Fig. 14.

8. Acknowledgements

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